SECTION II.—GENERAL METEOROLOGY.

PRESSURE IN ABSOLUTE UNITS.

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[Dated Dec. 16, 1913.]

From time to time, and especially within the last few years, the adoption of absolute units for representing atmospheric pressure has been urged on scientific grounds, and there is a general consensus of opinion that absolute units are the most suitable for dealing with meteorological theory, especially in relation to the upper air.

Through circumstances which are not altogether within my own control I have had to face the adoption of absolute units as a practical question and also as an educational question. In fact, I have had to ponder over replies to the following questions:

What units for pressure [and temperature] should be adopted in the publication of monthly values of pressure for a *réseau mondial?*

What units should be employed by lecturers and teachers who wish to interest students of mathematics and physics in the development of meteorological science?

What graduation should be employed for a barometer in order to commend most effectively to the wider public, the results of meteorological study?

I find the answer to all these questions in absolute units on the C. G. S. system, with only an outstanding uncertainty as to whether the millibar or the centibar is to be preferred.

Perhaps I had better explain that the *bar* represents the C. G. S. "atmosphere," that is, a pressure of 1,000,000 dynes per square centimeter, the dyne being the C. G. S. unit of force. The dyne is the force which produces an acceleration of 1 centimeter per second, per second, in a mass of 1 gram. The weight of m grams when the gravitational acceleration is g centimeters per second, per second, is mg dynes. The bar is approximately equivalent to 750 millimeters, or 29.5 inches, of mercury at 0° C. and standard gravity. The centibar is one hundredth, the millibar one thousandth, of the bar.

It is quite possible that I may be to some extent affected by unconscious bias in favor of the ultimate application of theory to practice. If absolute units are the best for theory, they are the units of the future; for the practical applications of meteorology must ultimately be guided by theory just as those of astronomy are at the present day. For me this supplies the answer to my first question. The time is coming, if it has not already come, when students of meteorology will deal with the earth as a whole on the basis of observations and will recognize that anything short of that is inadequate for the solution of the more general problems of climate and weather.

To my second question, as to what are the best units for educational purposes, there is only one answer. So far as my own country is concerned, in all schools and colleges, wherever the elements of mathematics, physics, and chemistry are instilled into the rising generation, they are in association with the metric system as a part of scientific education. Two consequences result therefrom: In the first place, a complete divorce of all scientific experience from the meteorological practice of everyday life, a divorce which may perhaps be sufficiently illustrated if I say that in the laboratory a water bath of 98° is a very different thing from bath water of 98° in everyday life. The whole of the disastrous effect of this divorce is hardly to be appreciated by those who have nearly accomplished their life's journey with comparative success in spite of that disadvantage, but that is no reason for disregarding its importance to the young, and therefore let me call special attention to another aspect of it.

Between professors and students of the mathematical and physical schools of our universities there is a "freemasonry," of which the use of metric units is a sign and from which the students of meteorology are apt to find themselves excluded. To express my meaning in the fewest words, let me say that if in a country assembly for the advancement of science, an unknown stranger should get up and speak in metric units, the initiated physicist would at once say "he must be one of *us*," and the uninitiated meteorologist would say "he is one of *them;*" but if he should begin his discourse by speaking in inches and grains, the physicists would at once say "we need not listen—there can be no dynamics or physics in this," and in the most out-of-the-way meteorological assembly, if anyone should be heard speaking in metric units, he would not be set down as an eccentric or a crank, but as a person with exceptional scientific associations.

This being so, what should be the line of action of a meteorologist who lays claim to some portion of the scientific spirit? Surely this—not to remain in the isolation that excludes us from the sympathy of fellow-workers, but to turn the tables upon our friends and say to the grand masters of our cult, "We will accept a metric system, but we can not accept your millimeter, because when we make a change we must take care not to perpetuate the unscientific practice of representing the pressure of the atmosphere by a length. We know that the millimeter which you use is not really a length at all, and is really only a millimeter under conventional conditions of temperature and latitude which never occur together, but our students, who have yet to learn that important fact, will have clearer ideas from the start if they do not begin with that confusion. We are prepared to do what physicists have often aspired to do, but have not had the courage or coherence to carry out, namely, to use pressure units for pressure measurements and leave length units to measure lengths with. Nor can we accept your centigrade scale with the freezing point of water as its zero. We can not let our students adopt the conception of negative temperatures, which is a survival of the time anterior to the conservation of energy and which has sooner or later to be explained away with much labor and practical inconvenience."

Let us now deal with the third question: What kind of barometer should be put before the general public with due regard for the teachings of modern meteorology?

We know that it is still the practice to sell barometers with the customary legends—

28.0	28.5	29.0	29.5	30.0	30.5	31.0 inches.
Stormy.	Much rain.	Rain.	Change.	Fair.	Set fair.	Very dry.

and that many newspapers reproduce day by day a barometer dial of this kind. On metric barometers we find the same legends, but "Change" is opposite to 760 millimeters instead of 29.5 inches and the steps are 10 millimeters instead of half inches. That is in itself sufficient condemnation of what on other grounds is quite intolerable, and in these days we want to suggest some alternative that will not spoil the instrument makers' trade nor yet convey to the countryman misleading ideas.

The first idea that an official meteorologist would suggest is that no countryman would have done his duty by the atmosphere unless he had compared his local reading with that of the corresponding issue of the daily bulletin. To do that he must reduce his readings to sea level, so, absolutely, the first requirement is a simple means for giving, with sufficient approximation, the sea-level pressure. The next idea to be inculcated is that the actual pressure of the atmosphere at the moment does not matter as a general rule, but only the changes which are taking place, and which can be watched locally with great advantage. What could be better for this purpose than to mark some point within the range of the barometer as 100 and note the differences from that point as percentages? Coming to details, it can only be regarded as providential that the point on the barometer against which the word "Change" is inscribed, being 29.5 inches, corresponds almost exactly with 100 centibars; consequently the temptation to use centibars and write 100 there is irresistible. Then obviously we must make the range of the dial or the tube big enough to show the changes which are to be expected in the district in which it is to be used, and the countryman will at once realize within what percentages of the middle value the pressure has varied in the past, and therefore may be expected to vary in the future. It is curious that 100 centibars, although not the mean value of the sea-level pressure, is in the middle of the usual range, and is, in fact, the middle line of the ordinary record sheet of a Richard barograph, which is marked 75 centimeters or 29.5 inches.

By way of suggesting that it is variations of the barometric pressure which count, and not the particular level, we can give the frequencies of occurrence of different barometric pressures, so that the observer can see for himself whether conditions are normal or exceptional, and so keep an eye on the working of his instrument as well as on the weather.

I have set out these suggestions in a *Land Barometer*, with a rotating circle for reduction to sea level. It is not necessary to enter into any further explanation; what is set out on the dial ought to be self-explanatory. But I ought to say a word about the frequencies. I can not now recall where I got the figures which are engraved on this first dial. I have made new figures for subsequent specimens, which give the average frequency of barometric minima below 100 centibars and maxima above 102 centibars, for Valencia, Aberdeen, and Kew combined. The figures are not applicable to any particular place without further inquiry, and their entry on the dial is a challenge to the observer to verify or improve them for his own locality.

With the *Sea Barometer* things are different. The observer has no daily weather chart at hand to show the distribution of pressure at sea level with which he can check the readings of his own barometer, and for any check he must rely upon the normals for his locality. Nor can frequencies of barometer values be easily given for a sailor whose course runs north or south. A barometer, on the pattern of the Land Barometer, for the transatlantic voyage might be made, but for the sailor who is not restricted to the transatlantic passage the normals for different latitudes along the thirtieth west meridian seem the most effective, and they are shown on the Sea Barometer dial.

These two barometer dials seem to suggest the centibar as the C. G. S. unit most likely to be useful in practice. So far no one has had any effective experience with instruments graduated to give pressure in absolute measure, and the millibar has given its name to the battlefield between the old and new, because it was adopted by Prof. Bjerknes as a substitute for the millimeter. Fortunately the difference between centibars and millibars is only the difference of a decimal point, and the practice as to observing and publishing may be allowed to shape itself as convenience in practice dictates.

While I am writing on the subject of absolute units I should like to add a word about the proposal of Prof. Bjerknes to record heights in "dynamic meters," which has given rise to fierce controversy. The quantity which it is really sought to express by the use of the term "dynamic meters" is the product gh, which is in fact the potential energy of unit mass at the height h. This quantity may quite appropriately be called the *geo-potential*, that is, the potential due to the earth's gravitational attraction at the height h. In the units which Prof. Bjerknes employs, the acceleration g becomes numerically 0.981 for latitude 45°, and if h is expressed in meters, gh differs from h by less than 2 per cent.

Thus the expression for the height in meters is numerically little different from the pressure of the *geo-potential* in what Prof. Bjerknes calls *dynamic meters*. The objection to the suggestion may be briefly expressed by saying that what is thought to be represented is not really height as generally understood, especially, for example, in a pilot balloon sounding, which is essentially a geometrical measurement, and the unit in which the geo-potential is expressed is not a *meter*, nor any fixed length; it has not the unitary "dimension" of a length.

The objection to changing the "dimension" of a unit by prefixing an adjective is perfectly sound, but it is really a curiosity of scientific literature to find the objection to the use of "dynamic meter" for the expression of geo-potential denounced as immoral in an article which stoutly upholds the use of the "time-honored millimeter" as a unit of pressure, without even an adjective as a warning to the unwary.

Mr. F. J. W. Whipple, of my Office, has proposed a solution of the difficulty which seems to me to meet the case in a satisfactory way. He points out that we have no special name for the unit of acceleration, and that in quoting the acceleration of gravity for a particular latitude we have to express it as, say, 981 centimeters per second, per second. He suggests the name *leo*, an abbreviation of the name of Galileo, of immortal memory in connection with gravitation, as a suitable name for the acceleration of a dekameter per second, and in this unit the acceleration of gravity in latitude 45° would be 0.981 *leo*. Then on the analogy of the *kilogram-meter* or the *foot-pound*, both time-honored as units of work or potential energy, a *leo-meter* would be the potential energy of unit mass raised through 1 meter against an acceleration of 1 "leo" or of unit mass raised through $1/g$ meters against the acceleration of gravity. Thus Prof. Bjerknes' "height" in *dynamic meters* would become the *geo-potential* in "*leo-meters*," and would differ numerically from the real height in meters only by about 2 per cent.

In this way all the objections on the score of morality or unsound terminology would be avoided, and yet the numerical value of the geo-potential in "leometers" would enable us to keep in mind a close approximation to the actual height in the consideration of the dynamic problems of the atmosphere.

It seems clear that the time has come when meteorologists may properly turn their attention to the reconsideration of their units and their nomenclature, and that the call comes with almost equal force from the theoretical, the educational, and the practical sides of their work.

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THE WINDS IN THE FREE AIR.[1]

By CHARLES J. P. CAVE, Esq., M. A., J. P., M. R. I.

[Dated April 11, 1913.]

It was noticed in very early times that the wind in the upper air may be very different from what it is on the surface. Lucretius says: "See you not, too, that clouds from contrary winds pass in contrary directions; the upper in contrary way to the lower?" Bacon advocated the use of kites in studying the winds; but it is only in quite recent years that any systematic attempt has been made to investigate the free air above the surface of the earth. Kites have been flown to a height of 4 miles, but it is a matter of some delicacy to get even as high as 2 miles.

The temperature of the free air may be recorded by a meteorograph attached to a small rubber balloon, which continues to ascend until the pressure of the gas inside bursts the envelope, and the instrument descends again to the surface. The beautiful instrument constructed by Mr. W. H. Dines, F. R. S., the pioneer of upper-air research in England, is so light that the torn fabric of the balloon is sufficient to act as a parachute and check the speed of decent.

The general result of the observations has been to show that the temperature of the air decreases with height up to a certain point, above which the temperature distribution is nearly isothermal; however much higher the balloon may ascend, there is little further change of temperature. This upper layer, discovered by M. Teisserenc de Bort, whose recent death meteorologists of every country lament, is called the stratosphere; the lower part of the atmosphere is the part that is churned up by ascending and descending convection currents and is called the troposphere. The height at which the stratosphere is reached, as well as the temperature of the layer, varies from day to day and from place to place. In England it is met with at heights varying from about 8 to 14 kilometers, with temperatures varying from $-40°$ to $-80°$ C.

It is not, however, with temperatures that I am chiefly concerned to-night, but with the wind currents in the different layers of the atmosphere. If one of the balloons carrying instruments or if a smaller pilot balloon is observed with a theodolite, its position from minute to minute can be determined, and from its trajectory or its path as it ascends the winds that it encounters can be calculated.

[1] Reprinted by permission of the author from the Proceedings of the Royal Institution of Great Britain.

The theodolite used is constructed specially for the purpose; a prism in the telescope reflects the light at right angles, so that the observer is always looking in a horizontal direction, even if the balloon is overhead. It is important that the observer should be in as comfortable a position as possible, for an ascent sometimes lasts over an hour and a half, during which time the observer can only take his eye from the telescope for a few seconds at a time; otherwise he may lose sight of the balloon and be unable to find it again.

The balloon having been started from one end of the base, observations are taken from both ends at exactly the same time, usually every minute. From the positions of the balloon at each successive minute, which are plotted on a diagram, the run of the balloon during the minute can be measured, and hence the wind velocity during that minute can be obtained. After the wind velocities have been measured off and the wind directions obtained from the directions of the lines on the diagram, another diagram is constructed showing the relation of the wind velocity and direction to the height.

It is not necessary to have two observers if the rate of ascent of the balloon is known; in such a case the complete path of the balloon can be calculated from the observations of one theodolite. It is not possible to know the rate of ascent with complete accuracy, as up and down currents in the air will affect the normal rate. In practice, especially in clear weather, the method is fairly satisfactory. The method of one theodolite requires less preparation, and the subsequent calculations of the path of the balloon are less laborious than in the case of observations taken with two theodolites from opposite ends of a base line.

The best time for observations is toward sunset, so that the balloon reaches its greatest height after the sun has set on the surface of the earth. At such times the balloon, still illuminated by the sun, shines like a planet; and on one occasion I should have found it impossible to tell which was the balloon and which was Venus except for the movement of the balloon. The distances at which balloons may be seen through the telescope of the theodolite are remarkable. A striking instance was when the flash of the sun on the small meteorograph was seen—not once, but repeatedly—when the balloon was about 9 miles above the sea and at a horizontal distance of about 30 miles.

In considering the structure of the atmosphere, as it has been revealed by the observations I have carried out, principally at Ditcham on the South Downs, we may divide the subject into two parts: (A) The wind structure in the lowest kilometer and (B) the general wind distribution up to the greatest heights reached by the balloons.

It is a matter of common observation that the wind increases above the surface, and in these days of aerial navigation it is important to know the law of this increase. It seems that at Ditcham the increase in velocity is at first linear or nearly so and that the line representing the linear increase passes through zero velocity at sea level; that is to say, if we plot the wind velocity at the surface and draw through it a line from zero velocity at sea level, the wind velocities at other heights, up to half a kilometer to 1 kilometer, will lie very nearly on this line. This approximately linear increase has been found to agree with observations at several land stations, but over the sea other conditions probably prevail.

But there are occasions when this state of things does not apply at all; this is often the case in light breezes and